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Competition and innovation: an experimental investigation

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Abstract The paper analyzes the effects of more intense competition on firms' investments in process innovations. More intense competition corresponds to an increase in the number of firms or a switch from Cournot to Bertrand competition. We carry out experiments for two-stage games, where R&D investment choices are followed by product market competition. An increase in the number of firms from two to four reduces investments, whereas a switch from Cournot to Bertrand increases investments, even though theory predicts a negative effect in the four-player case. The results arise both in treatments in which both stages are implemented and in treatments in which only one stage is implemented. However, the positive effect of moving from Cournot to Bertrand competition is more pronounced in the former case.

Keywords R&D investment · Intensity of competition · Experiment

JEL Classification C92 · L13 · O31

1 Introduction

Simple two-stage games are often used to derive predictions about the effects of increasing competition on cost-reducing investments.[1] Testing such predictions in the

[1] Schmutzler (2010) and Vives (2008) synthesize the existing literature.

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field is very difficult, and the literature comes to ambiguous conclusions.[2] Therefore, this paper uses laboratory experiments to explore whether at least the basic strategic effects identified in the theoretical models are present.

We consider four different games where two or four firms choose a cost-reducing investment before they engage in Cournot or Bertrand competition with homogeneous goods. Thus we can explore how increasing competition by increasing the number of players and by switching from Cournot to Bertrand competition affects investments.[3] To understand better what drives the results, we not only considered treatments with the two-stage structure of the underlying game, but we also analyzed one-stage treatments where subjects' investment decisions automatically result in the payoffs of the ensuing product-market subgame. This allows us to investigate whether deviations from the equilibrium investments in the two-stage game are driven exclusively by expected deviations in the product-market game. Our analysis leads to the following main insights.

(1) Investments decrease as the number of players increases.
(2) For a switch from Cournot to Bertrand competition, the observed effect on investments is positive.
(3) The positive investment effect of moving from Cournot to Bertrand competition arises even in the four-player case, where the predicted effect is negative.
(4) Even though all three results just described arise both for the one-stage and two-stage treatments, the positive effect of moving from Cournot to Bertrand is more pronounced for the two-stage treatments.

Result (1) confirms what has been observed by other authors in stochastic static and dynamic patent races (Isaac and Reynolds 1988, 1992). Cournot investment games have been studied by Suetens (2005), but only for duopoly markets.[4] Thus, the number effects of competition on investment have not been studied in a Cournot setting.[5]

The remaining results have not been observed elsewhere. Except for the unpublished working papers of Sacco and Schmutzler (2008) and Darai et al. (2009), we are not aware of any other contribution that deals with investment games under ho-

[2] See the references at the end of this section.

[3] In a related paper, Sacco and Schmutzler (2010) analyze the effects of increasing competition by changing the degree of substitutability in a differentiated product market. They expose a U-shaped relation in the underlying model, and they provide weak experimental evidence in favor of such a relation.

[4] Suetens (2005) focuses on the differences between investments and the Nash equilibrium, and specifically on the role of knowledge spillovers in this context. In Suetens (2008) the focus is on RJVs and their effect on price collusion in Bertrand competition with product differentiation. Again she only considers duopoly markets and the effects of increasing competition are not a matter of concern.

[5] Importantly, note that our analysis is distinct from the more familiar analysis of number effects in Cournot oligopolies (Huck et al. 2004; Orzen 2008). This literature deals with the effects on prices and quantities rather than on investments.

mogeneous Bertrand competition,[6] let alone with a comparison between Cournot and Bertrand investment games.[7]

Result (3) has also not been observed so far, but it is related to familiar overbidding results in the context of all-pay auctions, which are similar to Bertrand investment games.[8] Result (4) is of more general methodological value: It shows that, to understand behavior in two-stage games, it is useful to consider both the full two-stage game and the reduced one-stage version. In this fashion, one can identify the sources of deviations from the first-stage equilibrium choices more readily. Specifically, we show that first-stage overinvestment in the Bertrand case tends to go hand in hand with above-equilibrium prices in the second stage.

We see our experimental research as complementary to the existing field research, which comes to ambiguous conclusions about the effects of competition on investment. Broadly speaking, this ambiguity may reflect either small differences in the strategic environment or endogeneity problems. As to the former, Schmutzler (2010) emphasizes how the predicted effect of competition on investment depends on modeling details, which would suggest that ambiguous empirical results are merely the confirmation of ambiguous predictions. As to the endogeneity problem, it looms large in the early literature, surveyed in Cohen and Levin (1989). While this literature regarded market structure as an explanatory variable, the causality might run in the opposite direction.[9] Innovation may influence market structure because R&D involves fixed costs, because it affects the pattern of firm growth in an industry or changes the efficient scale of production. This endogeneity problem has been taken into account to some extent by the more recent literature. Nevertheless this literature is not very conclusive. For instance, Nickell (1996) obtains a positive effect of competition on investments. In Aghion et al. (2005), an inverted-U relationship between intensity of competition and investments arises. An experimental analysis addresses both problems: It allows us to delineate a setting in which the theoretical predictions are clear and there are no endogeneity problems.

The paper is structured as follows. Section 2 contains the theoretical framework. Sections 3–5 describe the experimental design and results. Section 6 concludes.

2 The model

We analyze static two-stage games, where firms $i = 1, \dots, I$ first invest in R&D and then compete in the product market. The demand function for the homogeneous product is given by $D(p) = a - p$, with $a > 0$. All firms i are identical ex-ante,

[6] Sacco and Schmutzler (2008) consider the reduced one-stage version of a two-stage Bertrand game, where investments precede price competition. They show that overinvestment is substantial. Overinvestment is also observed by Darai et al. (2009) where both stages are played out, but they focus on the incentive effects of policy instruments on investment. However, both papers do not deal with the effects of increasing competition.

[7] Suetens and Potters (2007) compare prices and outputs in Bertrand and Cournot games, but not investments.

[8] See Sect. 5 for a more careful discussion.

[9] For an introduction to more recent evidence on that matter, see Gilbert (2006).

with constant marginal costs $c > 0$. In the first stage, firms simultaneously choose R&D investments $Y_i \in [0, c)$, resulting in marginal costs $c_i = c - Y_i$. The cost of R&D is given by kY_i^2, where $k > 0$. In the second stage, firms simultaneously choose quantities (Cournot competition) or prices (Bertrand competition).

2.1 Cournot competition

For the Cournot case, backward induction shows that the net payoff function of firm i in the first stage is given by

$$\Pi_i(Y_1, \ldots, Y_I, \alpha, k) = \left(\frac{\alpha + IY_i - \sum_{i \neq j} Y_j}{I+1}\right)^2 - kY_i^2, \tag{1}$$

where $\alpha \equiv a - c$ represents the demand parameter.[10]

The gross payoff of firm i, that is, the first term on the right-hand side of (1), depends positively on its own investment and the demand parameter, and negatively on the investments of the other firms. The following result is immediate:[11]

Proposition 1 *Under Cournot competition the symmetric pure-strategy Nash equilibrium investment levels are*

$$Y^C = \frac{\alpha I}{k(I+1)^2 - I}. \tag{2}$$

By (2), equilibrium investments are increasing in the demand parameter α, and decreasing in the cost parameter k and in the number of firms I.

2.2 Bertrand competition

For Bertrand competition, backward induction shows that the net payoff function of firm i can be written as a function of efficiency levels as follows:

$$\Pi_i(\cdot) = \begin{cases} (Y_i - Y_{-i}^m)D(c - Y_{-i}^m) - kY_i^2, & \text{if } Y_i > Y_{-i}^m, \\ -kY_i^2, & \text{if } Y_i \leq Y_{-i}^m, \end{cases} \tag{3}$$

where $Y_{-i}^m = \max_{j \neq i} Y_j$. Compared to the Cournot case, competition is intense in the sense that a firm can achieve a positive gross payoff only by investing more than the highest investment of the others. If $Y_i > Y_{-i}^m$, maximizing (3) with respect to Y_i gives

$$\frac{\partial \Pi_i(\cdot)}{\partial Y_i} = D(c - Y_{-i}^m) - 2kY_i \equiv 0. \tag{4}$$

$Y_i \leq Y_{-i}^m$ can only be a best response if $Y_i = 0$ holds: If firm i does not invest more than all others, it gets a negative net payoff. In such a case the deviation to $Y_i = 0$ is

[10] Here and in the following, we assume that $\alpha + IY_i - \sum_{i \neq j} Y_j \geq 0$.

[11] We assume that the second order condition holds, that is, $I^2/(I+1)^2 - k < 0$, which is fulfilled for arbitrary $I \geq 2$ if $k \geq 1$.

profitable. The pure-strategy equilibrium is thus characterized as follows (Sacco and Schmutzler 2008, Proposition 7).

Proposition 2 (i) *Under Bertrand competition, for* $k > \frac{1}{2}$, *there are multiple asymmetric pure-strategy equilibria with one firm investing* $Y_i^B = \frac{\alpha}{2k}$ *and firms* $j \neq i$ *investing* $Y_j^B = 0$. (ii) *There are no other pure-strategy equilibria.*

Proposition 2 implies that the average investments are $\overline{Y}^B = \frac{\alpha}{2kI}$, which is increasing in α, and decreasing in k and in I. It is unlikely that agents can coordinate on one of the asymmetric pure-strategy equilibria. We therefore refer to the following result of Sacco and Schmutzler (2008).

Proposition 3 *The investment game with Bertrand competition has a symmetric mixed-strategy equilibrium, where firms mix between all strategies up to a cut-off level.*[12]

Of course, one may be concerned with the relevance of mixed-strategy equilibria in the context of an oligopoly with a small number of players. We clearly do not expect decision makers in firms to randomize deliberately. Also, the common justification that mixed-strategy equilibria describe behavior in large populations of players, each of which takes non-random decisions, makes no sense in our context. A more convincing a priori justification relies on standard purification arguments (Harsanyi 1973).[13]

2.3 The effects of increasing competition

We now consider the predicted effects of competition on investment.

Corollary 1

(i) *The average equilibrium investments are decreasing in* I *for both Bertrand and Cournot competition.*
(ii) *Suppose that* $k > \max\{\frac{1}{2}, \frac{I^2}{(I+1)^2}\}$. *The average equilibrium investment for Cournot is higher than the average investment in each asymmetric pure-strategy equilibrium for Bertrand for* $I \geq 3$. *For* $I = 2$, *average investments are higher for Bertrand unless* $k \leq 2$.

Though we cannot provide such results for the mixed-strategy equilibrium at this level of generality, a similar statement holds for the parameters we choose (see

[12] The game also has asymmetric mixed-strategy equilibria where some firms always play zero and others randomize.

[13] Specifically, one can consider a Bayesian game with a continuum of players with statistically independent types, reflecting small differences in payoffs. The mixed-strategy equilibrium of the complete information game is then close to the equilibria of nearby Bayesian games.

Sect. 3.2). Thus, except for the caveat for $I = 2$, for both concepts of competitiveness, an increase in competition reduces investment.

Both of these changes in the competitive environment have the common feature that they correspond to reductions in the mark-ups that firms can command in the product market equilibrium. To see the crucial difference, note that an increase in the number of competitors in a Cournot setting has a fairly smooth effect on the nature of competition. Most importantly, both firms can obtain positive profits before and after the change in competition. As one moves from Cournot to Bertrand, the change in the competitive environment is more dramatic: It is well known that at most one firm can obtain a positive profit in the Bertrand investment game when both firms choose equilibrium prices in the ensuing subgame; so that competition is of a winner-takes-all nature. Thus, without correct expectations about competitor investments players may easily take very bad decisions. The Bertrand game has multiple asymmetric pure-strategy equilibria, a symmetric mixed-strategy equilibrium and even asymmetric mixed-strategy equilibria. It is not obvious how players coordinate in a static setting. We use the mixed-strategy equilibria as the benchmark to predict equilibrium investments in the Bertrand game, whereas we resort to the symmetric pure-strategy equilibrium in the Cournot case.

3 Experimental design

We now describe the treatments, the parameters and the hypotheses.

3.1 Treatments

We conducted eight treatments (see Table 1), which differed in the following three dimensions:

1. The number of players (two vs. four)
2. The mode of competition (Bertrand vs. Cournot)
3. The number of stages played out (one vs. two)

The need for the first two treatment variations is obvious given our questions of interest. The third point requires some clarification. To capture the models introduced in Sect. 2 accurately, the two-stage treatments are adequate and, arguably, they are also more realistic. However, in such treatments, there may be confusion about the source of possible deviations from the equilibrium in the investment game. Broadly,

Table 1 Treatments

Number of players	Type of competition	
	Bertrand	Cournot
$I = 2$	B2, 2 sessions	C2, 2 sessions
$I = 4$	B4, 2 sessions	C4, 2 sessions

For each treatment we ran two sessions, one with one stage and one with two stages played out one can imagine two classes of deviations. First, subjects may be expecting non-equilibrium behavior in the product market stage.[14] For instance, they might believe that all parties (including themselves) collude below the equilibrium output in the Cournot game, in which case they should rationally choose lower than equilibrium investments in the first stage. Second, even when they do not expect such deviations in the product market game, players may want to deviate from equilibrium investments for other reasons. For example, they might realize that investments involve negative externalities, and they may want to coordinate on lower investments that make all players better off.

To identify which of these two types of deviations arise, we conducted all treatments in two different versions which we call one- and two-stage treatments. In the latter, subjects play the product market game as well as the investment game. In the one-stage treatments subjects only choose investment levels, and payoffs for each choice of investments correspond to the payoffs in the equilibrium of the ensuing product market subgame by assumption. Thus deviations from equilibrium cannot result from expected deviations in the product market game. Thereby we can identify to which extent deviations in the two-stage game are attributable to each source of deviations.

3.2 Parameters and predictions

We chose parameter values $\alpha = 30$ and $k = 3$. We restricted the strategy sets to $Y_i \in \{0, 1, \dots, 9\}$. Restricting choices to discrete strategies had two main advantages. First, we could present information on payoffs (gross of investment costs) in simple matrices. Second, in this fashion, the integers no longer play the role of prominent numbers.

The downside is that the equilibria of the discrete game reflect the negative effect of increasing the number of players on investments only imperfectly. For some parameters, increases in the number of players have no effect. For instance, equilibrium investments are $(2, 2)$ for the two-player Cournot game and $(2, 2, 2, 2)$ for the four-player game. While the equilibria of the discrete game are the more natural benchmark for individual behavior given the discrete strategy sets, it will turn out to be instructive to compare *average* behavior with the corresponding continuous games. The equilibria for these games are $(2.4, 2.4)$ and $(1.69, 1.69, 1.69, 1.69)$, so that the investment effect of increasing the number of players is negative.

For Bertrand competition, there is no such problem: According to Proposition 2, there are asymmetric equilibria, each with one firm investing 5 and the other firm(s) 0. This holds both for the discrete and continuous strategy set. Moreover, using the formulas provided by Sacco and Schmutzler (2008), one can show that the two-player game has a symmetric mixed-strategy equilibrium (MSE) given by

$$(p_0, \dots, p_9) = (0.1, 0.193, 0.187, 0.182, 0.176, 0.160, 0, 0, 0, 0). \tag{5}$$

[14] Such deviations are known to arise both in the Bertrand (Dufwenberg and Gneezy 2000) and in the Cournot case (Huck et al. 2004, and many others).

Table 2 Equilibria

Model	Equilibrium investment		
	discrete	continuous	mixed
Cournot $I=2$	(2, 2)	(2.4, 2.4)	–
Cournot $I=4$	(2, 2, 2, 2)	(1.69, 1.69, 1.69, 1.69)	–
Bertrand $I=2$	(5, 0)	(5, 0)	(2.62, 2.62)
Bertrand $I=4$	(5, 0, 0, 0)	(5, 0, 0, 0)	(1.27, 1.27, 1.27, 1.27)

For the mixed equilibria we show expected investment levels, see (5) and (6)

For the four-player game, the symmetric MSE is given by

$$(p_0, \dots, p_9) = (0.464, 0.2, 0.119, 0.088, 0.071, 0.057, 0, 0, 0, 0). \tag{6}$$

The expected investment levels (2.62 for the two-player and 1.27 for the four-player Bertrand game) are close to the average investments ($\overline{Y}^{B2} = 2.5$; $\overline{Y}^{B4} = 1.25$) of the pure-strategy equilibria.

Table 2 provides an overview of the equilibrium investments.

We use the equilibrium predictions to derive the following hypotheses about the effects of increasing competition.

Hypothesis 1 *Increasing competition in the sense of switching from two to four players has a non-positive effect on investments in the Cournot case and reduces investments in the Bertrand case.*

The *non-positive* effect on investments in the Cournot case is consistent with the prediction of no effect from the discrete game and of a negative effect from the continuous game.

Hypothesis 2 *Increasing competition in the sense of switching from Cournot to Bertrand competition increases investments in the two-player case and reduces investments in the four-player case.*

The two predictions of Hypothesis 2 can be derived by using the equilibria of the discrete game as well as those of the continuous game. They hold for the asymmetric pure-strategy equilibria and the symmetric MSE.

3.3 Subjects and payments

The experimental sessions were conducted between November 2008 and February 2009 at the University of Zurich. The participants were undergraduate students.[15]

[15] We did not exclude any disciplines. We had students of law, engineering, psychology, economics etc.

We implemented four sessions with Bertrand treatments, and four with Cournot treatments (see Table 1). Two of the Bertrand and two of the Cournot sessions were two-player treatments. In each session there were 20 periods. No subject participated in more than one session. The four-player sessions had 32 subjects; each two-player session had 36 subjects. The 36 (32) subjects of the two-player (four-player) treatments were randomly divided in matching groups of four (eight) subjects each at the beginning of the experiment. Within the matching groups we applied the stranger design, i.e. randomly rematched subjects into groups of two (four) after each period.[16] Thus, we obtained nine (four) independent observations per two (four)-player session. Sessions lasted about 90 minutes each.

At the end of each period, subjects were informed about the investment of the other subject(s) in their group and their own net payoff for that period. When the second stage was played out, they were informed about the investment of the other subject(s) in their group before choosing price or quantity and after the second stage they also learned the price or the quantity decision of the other group member(s). Participants received an initial endowment of CHF 35 ($\approx$EUR 23). Average earnings including the endowment were between CHF 30 ($\approx$EUR 20) and CHF 36 ($\approx$EUR 23) for the Bertrand sessions and between CHF 39 ($\approx$EUR 26) and CHF 49 ($\approx$EUR 33) for the Cournot sessions. The experiment was programmed and conducted with the software z-Tree (Fischbacher 2007) and subjects were recruited using ORSEE (Greiner 2004).

4 Results

In Sect. 4.1 we provide a brief overview of the results. In Sect. 4.2, we look at our hypotheses in more detail.

4.1 Overview

Here and in the following, we always use matching group averages as independent observations. Kruskal-Wallis tests reveal that we can reject the hypothesis that the investment levels of all treatments, of all one-, or of all two-stage treatments are drawn from the same population.[17]

Figure 1 illustrates how investments vary across treatments. Each panel contains the average per-period investments for one of the four cases, distinguishing between the one-stage and the two-stage treatments. It also shows the equilibrium investments.[18] Based on this descriptive evidence, we arrive at the following tentative conclusions.

[16] Thanks to the matching group approach, we obtain sufficiently many independent observations while reducing the possibility of repeated game behavior. Nevertheless, subjects may "learn" from the past prices/quantities chosen by the other players in their matching groups. Modeling how the firms arrive at their beliefs about the other player's future prices when they choose investments is beyond the scope of this paper, however.

[17] The null-hypothesis of no differences is rejected with a p-value of 0.000, if all treatments are considered. If we take only the one (two)-stage treatments into account the p-value is 0.006 (0.000).

[18] In the Cournot case, we depict the equilibria of the continuous game; recall that the equilibria for the discrete game are $(2, 2)$ and $(2, 2, 2, 2)$, respectively.

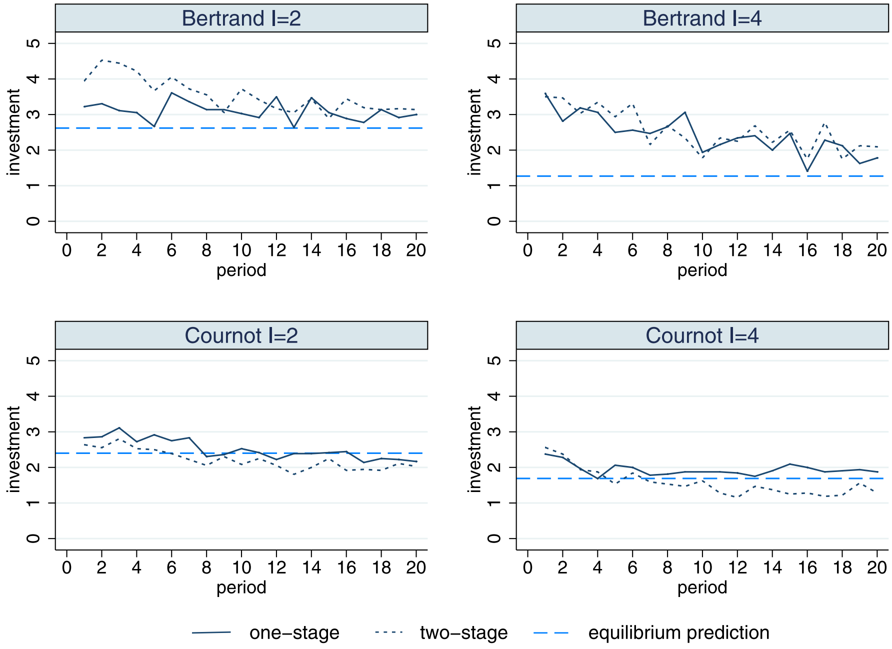

Fig. 1 Average investment per period

1. Increasing the number of players leads to lower average investments in the Cournot and the Bertrand case.[19]
2. Moving from Cournot to Bertrand competition leads to greater average investments for the two-player and four-player treatments.[20]
3. For the four-player case, the positive effect of moving from Cournot to Bertrand competition holds even though the predicted effect is negative.[21]

[19]These results are supported by pairwise Mann-Whitney-U tests. We find significant differences between C2 and C4 as well as between B2 and B4. One-tailed tests reject the null hypothesis of no differences in average investments in favor of higher investment levels in C2 (B2) than in C4 (B4) at a p-value of 0.025 (0.048) for the one-stage treatments, and respectively at a p-value of 0.010 (0.003) for the two-stage treatments. Pooling the data of the one- and two-stage treatments results a p-value of 0.001 (0.000).

[20]The result for the two-player case is supported by a one-tailed Mann-Whitney-U test for the two-player one-stage ($p = 0.005$) and two-stage treatments ($p = 0.000$) and for the pooled data ($p = 0.000$). For the four-player case, a two-tailed Mann-Whitney-U test does not reject the hypothesis of no differences in investment levels between the two four-player one-stage treatments with a p-value of 0.200. For the two-stage treatments it rejects the null with a p-value of 0.029 and for the pooled data with a p-value of 0.001 if we pool the data. However the mean ranks are always higher in B4 than in C4.

[21]This predicted negative effect holds not only for the equilibrium of the continuous Cournot game depicted Fig. 1, but also for the equilibrium of the discrete Cournot game, where average investments are 2 and thus higher than in the Bertrand MSE (1.27).

4. The positive investment effect of moving from Cournot to Bertrand competition is more pronounced in the two-stage treatments.[22]

4.2 Comparative statics

We now analyze the comparative statics effects in more detail.

4.2.1 Number effects

To investigate the number effects, we consider OLS models[23] of all Cournot treatments as well as of the one- and two-stage treatments separately; similarly for the Bertrand case. The model is given by

$$y_t^i = \beta_0 + \beta_1 \delta_{I4}^i + \sum_{s=1}^{3} \beta_{s+1} \delta_{Ps}^i + \beta_5 \delta_{one\text{-}stage}^i + \beta_6 \delta_{I4*\,one\text{-}stage}^i + e_t^i, \qquad (7)$$

where δ_{I4}^i is a dummy variable for intense competition (four players rather than two), and $\delta_{P_s}^i$ are dummy variables for the first, second, and third quarter of periods. When we use the data of all treatments, we consider two additional dummy variables $\delta_{one\text{-}stage}^i$ which is equal to one for the one-stage treatments and $\delta_{I4*one\text{-}stage}^i$ which captures the interaction effect between the number of players and the type of treatment.

Table 3 shows that the estimated coefficient for β_1 in the one-stage Cournot model is -0.575 and highly significant. For the two-stage treatments, we obtain a highly significant β_1 of -0.648. Thus, the comparative statics are essentially the same in one-stage and two-stage treatments.[24] This result is supported by an insignificant stage and interaction effect if we pool the data. Finally, for both the one-stage and the two-stage treatments, we see that investments decrease over time.

For the Bertrand treatments, the effect of the number of players on investments has the predicted sign and is significant for the one- and two-stage treatments.[25] But the stage effect in the third Column is significant and negative. The interaction effect is insignificant which means that the number effect does not differ between the one- and two-stage treatments. Again we find that investment levels are significantly higher in earlier periods.

Summing up, we obtain the following confirmation of Hypothesis 1.

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[22]In the C2 one (two)-stage treatment we observe average investments of 2.51 (2.22) and 1.94 (1.57) in the C4 treatment. However, in the B2 one (two)-stage treatments we observe average investments of 3.10 (3.55) and 2.42 (2.56) for B4 treatments.

[23]We correct the standard error for matching group clusters in all OLS models presented in the following.

[24]Using a t-test, we cannot reject the null-hypothesis of no difference between the two estimated coefficients ($|t| = 0.2790$).

[25]Running a t-test reveals that the difference between the two estimated coefficients is not significant ($|t| = 0.8865$).

Table 3 Number effects in Cournot and Bertrand treatments

	investment (1-stage)		investment (2-stage)		investment (1- and 2-stage)	
Cournot Treatments						
I4	-0.575^{c}	(0.186)	-0.648^{c}	(0.184)	-0.648^{c}	(0.180)
$P_{1st\text{-}quarter}$	0.415^{b}	(0.138)	0.682^{c}	(0.149)	0.549^{c}	(0.107)
$P_{2nd\text{-}quarter}$	0.141	(0.103)	0.265^{c}	(0.068)	0.203^{c}	(0.063)
$P_{3rd\text{-}quarter}$	0.053	(0.069)	0.047	(0.044)	0.050	(0.040)
one-stage					0.296	(0.178)
I4*one-stage					0.073	(0.256)
constant	2.362^{c}	(0.112)	1.970^{c}	(0.106)	2.018^{c}	(0.120)
R^2	0.082	$(N = 1360)$	0.113	$(N = 1360)$	0.114	$(N = 2720)$
Bertrand Treatments						
I4	-0.675^{b}	(0.293)	-0.992^{c}	(0.205)	-0.992^{c}	(0.201)
$P_{1st\text{-}quarter}$	0.626^{a}	(0.313)	1.044^{c}	(0.178)	0.835^{c}	(0.178)
$P_{2nd\text{-}quarter}$	0.491^{a}	(0.275)	0.382^{b}	(0.131)	0.437^{c}	(0.150)
$P_{3rd\text{-}quarter}$	0.294^{b}	(0.100)	0.135	(0.173)	0.215^{b}	(0.099)
one-stage					-0.451^{b}	(0.207)
I4*one-stage					0.317	(0.351)
constant	2.744^{c}	(0.161)	3.158^{c}	(0.149)	3.177^{c}	(0.172)
R^2	0.026	$(N = 1360)$	0.078	$(N = 1360)$	0.051	$(N = 2720)$

Standard errors in parentheses are corrected for matching group clusters

[a] $p < 0.1$, [b] $p < 0.05$, [c] $p < 0.01$

Result 1 *For Cournot and Bertrand competition, investments are higher for two than for four players. Even though investment levels in one-stage and two-stage treatments differ, there is no significant difference in the size of the number effect across treatments.*

4.2.2 Cournot vs. Bertrand

We now consider the effect of moving from soft Cournot to intense Bertrand competition, considering OLS models of the one-stage and two-stage treatments separately and jointly. The models include $\delta^i_{Bertrand}$ as a dummy variable for intense (Bertrand) competition and dummy variables $\delta^i_{P_s}$ for the first, second, and third quarter of periods. $\delta^i_{one\text{-}stage}$ is a dummy variable for the one-stage treatment and $\delta^i_{Bertrand*one\text{-}stage}$ is the interaction effect between the type of competition and treatment.

$$y^i_t = \beta_0 + \beta_1 \delta^i_{Bertrand} + \sum_{s=1}^{3} \beta_{s+1} \delta^i_{Ps} + \beta_5 \delta^i_{one\text{-}stage} + \beta_6 \delta^i_{Bertrand*one\text{-}stage} + e^i_t. \quad (8)$$

Table 4 Effects of the type of competition in two- and four-player treatments

	investment (1-stage)		investment (2-stage)		investment (1- and 2-stage)	
Two-Player Treatments						
Bertrand	0.583[c]	(0.170)	1.331[c]	(0.217)	1.331[c]	(0.213)
$P_{1st\text{-}quarter}$	0.386[a]	(0.199)	0.783[c]	(0.201)	0.585[c]	(0.144)
$P_{2nd\text{-}quarter}$	0.311	(0.215)	0.317[b]	(0.123)	0.314[b]	(0.122)
$P_{3rd\text{-}quarter}$	0.147[b]	(0.067)	0.033	(0.129)	0.090	(0.072)
one-stage					0.296	(0.177)
Bertrand*one-stage					−0.747[c]	(0.271)
constant	2.303[c]	(0.138)	1.935[c]	(0.126)	1.971[c]	(0.131)
R^2	0.028	($N = 1440$)	0.185	($N = 1440$)	0.094	($N = 2880$)
Four-Player Treatments						
Bertrand	0.483	(0.310)	0.986[c]	(0.172)	0.986[c]	(0.166)
$P_{1st\text{-}quarter}$	0.672[a]	(0.298)	0.953[c]	(0.122)	0.813[c]	(0.160)
$P_{2nd\text{-}quarter}$	0.322	(0.227)	0.331[c]	(0.076)	0.327[b]	(0.115)
$P_{3rd\text{-}quarter}$	0.203	(0.128)	0.156	(0.123)	0.180[a]	(0.086)
one-stage					0.369[a]	(0.186)
Bertrand*one-stage					−0.503	(0.342)
constant	1.640[c]	(0.190)	1.210[c]	(0.142)	1.241[c]	(0.150)
R^2	0.030	($N = 1280$)	0.088	($N = 1280$)	0.060	($N = 2560$)

Standard errors in parentheses are corrected for matching group clusters

[a] $p < 0.1$, [b] $p < 0.05$, [c] $p < 0.01$

Table 4 summarizes the results. In all three models, the effect of competition on investment is positive and highly significant for the two-player case. In the four-player case the result is positive and significant for the two-stage treatments.[26]

Result 2 *Mean investments are higher for the Bertrand game than for the corresponding Cournot games.*

In the four-player game this contradicts the equilibrium prediction that investments are lower for the Bertrand case.[27]

Result 3 *In the four-player case, the positive investment effect of moving from Cournot to Bertrand competition arises even though the predicted effect is negative.*

[26]The period dummies show that investments decrease significantly as time goes by, independent of the data selection.

[27]The predicted effect is negative: In the continuous game, the effect is $1.27 - 1.69 = -0.42$; in the discrete game it is $1.27 - 2 = -0.73$.

Next, compare one-stage and two-stage treatments. In the two-player as well as the four-player case, β_1 is larger for the two-stage treatments. The difference is significant for the two-player case ($|t| = 2.7135$), but not for the four-player case ($|t| = 1.4188$). This is also shown by the highly significant interaction term in the two-player case, i.e. the effect of Bertrand competition on investment is different for one- and two-stage treatments. With this qualification, we summarize:

Result 4 *The effect of moving from Cournot to Bertrand competition tends to be more positive for two-stage than for one-stage treatments.*

5 Understanding overinvestment

We now investigate why the effect of moving from Cournot to Bertrand competition (i) is positive even when the prediction is that it is negative and (ii) is more pronounced in the two-stage treatments. We consider the OLS regression

$$\Delta y_t^i = y_t^i - y_t^{i*} = \beta_0 + e_t^i, \tag{9}$$

with y_t^{i*} standing for the predicted investment. If subjects invest according to the prediction, the estimated constant β_0 should be zero. The results for all treatments are presented in Table 7 in the Appendix.

The most important observation is the highly significant overinvestment in all two-and four-player Bertrand treatments. The overinvestment is significantly higher ($|t| = 2.108$) in the two-player two-stage treatments than in the one-stage treatments and significantly higher ($|t| = 2.105$) in the one-stage four-player than in the one-stage two-player treatments. The Cournot case essentially confirms the equilibrium prediction for the continuous model (see Table 3), whereas in the two-player discrete model there is overinvestment. The fact that the continuous model is a better predictor for average investments than the discrete model is worth emphasizing. To understand why the switch from Cournot to Bertrand tends to have a strong positive effect on investments, however, one mainly has to find out what lies behind the overinvestment in the Bertrand case. Further, one needs to understand why the overinvestment is more pronounced for the two-stage treatments.

Before we deal with these issues, note the relation between our overinvestment and the overbidding observations that have emerged in the literature on all-pay auctions. In a Bertrand investment game, even when all players invest a positive amount, only one player can earn positive profits if second-period equilibrium prices are set. However, contrary to standard all-pay auctions, the size of the bids affects not only the chances of winning, but also the prize. In particular, at least in the one-stage version, when the difference to the second-highest bid is close to zero, so is the winner's prize. In spite of these differences in the strategic setting, our overinvestment results are similar to the overbidding that arises in fixed-prize all-pay auctions.[28]

[28]Most closely related is Gneezy and Smorodinsky (2006) who consider symmetric all-pay auctions with 4, 8, and 12 players and also observe overinvestment. Like us, these authors obtain overbidding that diminishes over time, but remains substantial even in later periods. See also Davis and Reilly (1998).

5.1 Reasons for overinvestment

To understand overinvestment in the Bertrand case, consider the following evidence.

(1) Investments decrease strongly over time.
(2) There is substantial cross-player heterogeneity.
(3) In the four player-treatments, players obtain negative profits on average in all periods, but the losses are decreasing over time. In the two-player treatments, average profits are mostly positive.
(4) Compared to the MSE, the overinvestment comes mainly from too low weight on low positive strategies rather than too low weight on zero.

Point (1) has already been made in Sect. 4.2.

Point (2) is illustrated in Fig. 2. This figure is a histogram of average per-player investments in the four Bertrand treatments. The heterogeneity across players is substantial.[29] As to (3), consider Fig. 3, which shows how profits developed over times

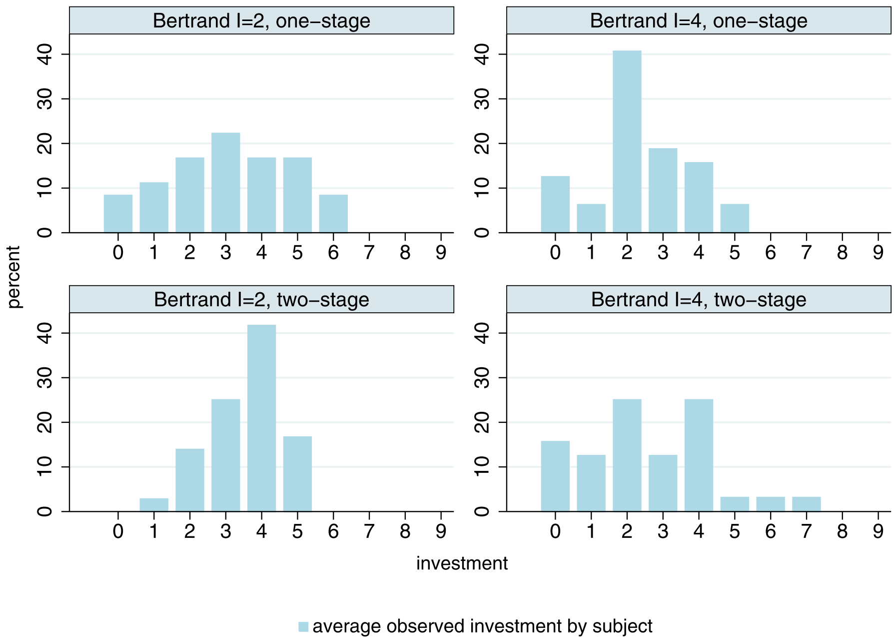

Fig. 2 Average observed investment per subject for all Bertrand treatments

[29] A figure with all individual investment paths (available in the Web Appendix) reveals substantial variety in another dimension: A considerable fraction of the players had one or two preferred investment choices that were chosen at least half the time. Almost as many players hardly ever chose the same investment level twice in a row.

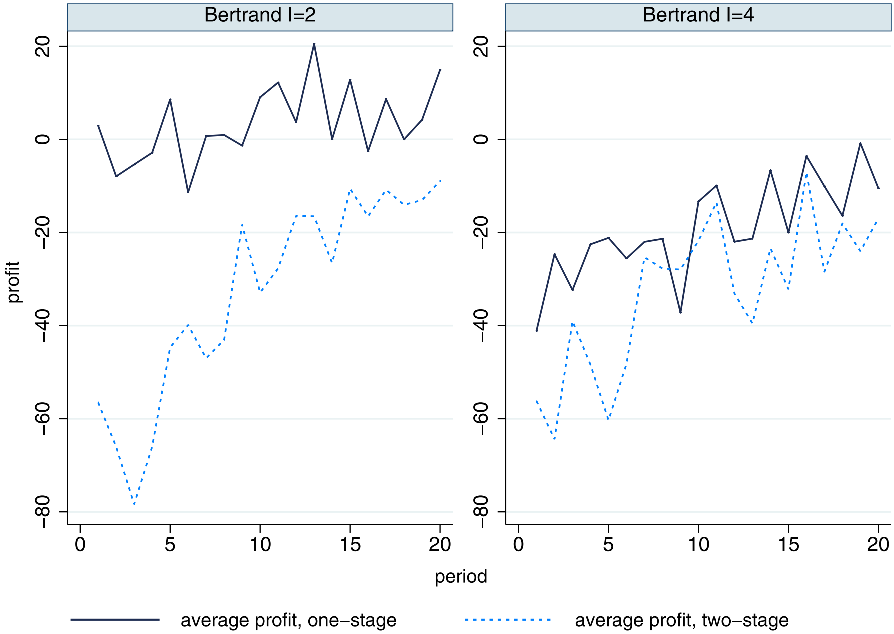

Fig. 3 Average profits over time of all Bertrand treatments

for the one- and two-stage case. The differences between the two-player and the four-player case are evident.[30]

Figure 4 in the Appendix confirms (4). In all treatments, subjects choose 1 and 2 much less frequently than in the MSE. The differences for zero investments are much smaller, and in one case (B2, one-stage) there are more zero investments than predicted by the MSE.

Our observations suggest a number of possible explanations for the overinvestment, all of which would apply both in the one-stage and the two-stage treatments.

1. *Joy of winning*: Subjects do not care exclusively about monetary payoffs, but derive an independent benefit from winning the game.
2. *Efficiency considerations*: Subjects deviate from equilibrium in order to come closer to joint-payoff maximization.[31]
3. *Reputation effects*: Subjects hope to induce others to refrain from investing.
4. *Confusion*: Subjects are at least initially unaware of the high risk of making losses with high investment choices.
5. *Optimism*: Subjects are aware of the possible losses, but overestimate the chances that others choose lower investments.

[30] A two-tailed Mann-Whitney-U test rejects the null hypothesis of no differences between the one- and two-stage two-player treatments ($p = 0.000$), but the test cannot reject the null hypothesis in the four-player case ($p = 0.200$).

[31] See, e.g., Engelmann and Strobel (2004).

Given the heterogeneity of individual profiles, it seems unlikely that a single explanation applies to all players. *Joy of winning*, for instance, is consistent with the observation that subjects tend not to choose low investment levels if they invest at all.[32] However, because of the substantial reductions in investments over time,[33] joy of winning cannot explain all observations. *Efficiency considerations* are not an entirely convincing explanation either. At least for $I = 4$, the deviations from equilibrium reduce joint profits (which are zero in expectation in the MSE). For $I = 2$, however, in most periods, average profits are positive, so that subjects indeed come closer to joint-profit maximization.

Among the other explanations, the appeal of *reputation effects* is limited: player identities were not common knowledge. The other explanations all have some merits. Players invest a lot and earn negative profits in early periods, which is consistent both with *confusion* and excessive *optimism* that fade away over time. Also, it is suggestive that these effects are stronger in the four-player case, where the strategic uncertainty is compounded by the fact that three opponents are present in each period. Finally, as Fig. 4 shows, 10–15% of the investments in all Bertrand treatments are weakly dominated strategies (6 or higher), also suggesting some degree of confusion.

Although we can rule out that overinvestment results *exclusively* from anticipated deviations in the two-stage game, we still have to explain why the comparative-statics effect is more pronounced in the two-stage case than in the one-stage case.

5.2 The role of the second stage

In the four-player games, averaging over all subgames, the observed output in the Bertrand (Cournot) case is only 1% (4%) lower than predicted.

For arbitrary investment decisions, the subgame equilibrium for Bertrand competition leads to higher market outputs than for Cournot competition. Consistent with this prediction, market outputs are higher in the Bertrand treatments than in the Cournot treatments, after controlling for average investments.[34] There are 14 different average investment levels that arise both in the Bertrand and the Cournot case. In 12 of these cases, the Bertrand outputs are higher than the Cournot outputs. Nevertheless, outputs tend to be lower than in equilibrium in the Bertrand treatment.

Analyzing individual behavior in the second stage, however, is more informative than considering only aggregate behavior. The key insight is that deviations from equilibrium ("collusion") in the second stage have different effects on the first period actions in the Cournot and in the Bertrand cases. In the Cournot case, collusion means that subjects choose lower outputs than in equilibrium in the second stage. Anticipating this, the value of investment is lower than it would be with equilibrium outputs.

[32] This argument is closely related to Sheremeta (2010) who allows for joy of winning in the utility function in an analysis of contests and provides experimental evidence for it.

[33] See regression results in Sect. 4.2.

[34] In the Bertrand case (not in the Cournot case), the average equilibrium outputs may depend on the precise investment profile rather than merely on average investments. A clean comparison of market outputs would therefore condition on investment profiles rather than on averages. However, there are very few investment vectors that were chosen both in the Cournot and in the Bertrand treatments, so that this approach is not informative.

Table 5 Deviation from the equilibrium price p^* in Bertrand two-stage treatments

	$c_i < \min\{c_{-i}\}$	$c_i = \min\{c_{-i}\}$	$c_i > \min\{c_{-i}\}$	$\sum$
Two-Player Treatment				
$p_i < p^*$	16%	4%	11%	12%
$p_i = p^*$	31%	64%	34%	39%
$p_i > p^*$	53%	32%	54%	49%
N	287	146	287	720
Four-Player Treatment				
$p_i < p^*$	12%	8%	7%	8%
$p_i = p^*$	28%	64%	54%	49%
$p_i > p^*$	60%	28%	39%	43%
N	139	50	451	640

Note: p^* comprises both the continuous and the discrete equilibrium.

Thus, if subjects plan to set low outputs, they invest less in the two-stage game than in the one-stage version.

In the Bertrand case on which we focus here, the role of the second stage is much more subtle. A firm always runs the risk that there is another firm with a lower price, so that investments may be useless. Its willingness to invest will depend on how it perceives this risk—a firm will invest only if it is sufficiently confident that its competitors will not set lower prices than itself. Modeling how the firm arrives at its beliefs about the other players' future prices when it chooses investments is beyond the scope of this paper. But suppose there is some exogenous difference in the firms' "optimism". Optimistic firms believe that their competitors will not set prices aggressively, and they will therefore put a high probability on the chance of winning even with a substantial own mark-up. Firms that are more optimistic than others—for whatever reason—should thus set high prices (because they expect to get away with it) and choose high investments (because they put a high probability on winning in spite of high prices).

Closer analysis of the data shows that this is precisely what happens. To see this, first consider Table 5 which shows that prices above the subgame equilibrium[35] p^* are indeed quite common.[36] In particular, 53% (60%) of the firms with the lowest marginal costs set prices above p^* in the two (four)-player treatment.

Table 6 elaborates on this by giving the average investments both for the case that prices are below or essentially at the equilibrium ($p_i \leq p^*$) and the case of above-equilibrium prices ($p_i > p^*$). In the former case, investments tend to be lower than in the latter. This confirms the interpretation that above equilibrium ("collusive") prices and high investments tend to go together.

[35]The second stage of the discrete Bertrand game has the following subgame perfect equilibria: (i) if $c_i = \min\{c_{-i}\} - 1$ or $c_i = \min\{c_{-i}\}$, then $p_i^* = c_i$ or $p^* = c_i + 1$; (ii) if $c_i < \min\{c_{-i}\} - 1$, then $p_i^* = c_{-i} - 1$; (iii) if $c_i > \min\{c_{-i}\}$, then $p_i^* \geq c_i$.

[36]Note, however, that we observe successful collusion in merely 12% (9%) of the two (four)-player markets. In those collusive markets both players in the two-player treatment or the two players with the lowest marginal cost in the four-player treatment set the same price above p^*.

Table 6 Average investment in Bertrand two-stage treatments

	$c_i < \min\{c_{-i}\}$	$c_i = \min\{c_{-i}\}$	$c_i > \min\{c_{-i}\}$	$\sum$
Two-Player Treatment				
$p_i \leq p^*$	4.07	3.38	1.54	2.98
$p_i > p^*$	5.22	4.32	3.01	4.13
Four-Player Treatment				
$p_i \leq p^*$	4.78	2.81	0.34	1.25
$p_i > p^*$	6.36	4.93	3.29	4.32

Note: p^* comprises both the continuous and the discrete equilibrium.

We finally add some brief comments on the Cournot investment game. We consider the four-player game. Interestingly, when the average investments are close to the equilibrium prediction, the same is true for market outputs in the second stage.[37] More generally, there is a clear and significant relation between outputs and investments. When we regress the outputs of a firm over own investments and competitor investments, the former have a positive effect, whereas the latter have a negative effect.[38] Both of these effects are consistent with the theoretical prediction, but smaller. Intuitively, the marginal effect of higher output on profits increases when own costs are low and decreases when competitor costs are low (because low-cost competitors produce a higher output and hence market prices are lower). Conversely, the value of investing is higher when one expects to produce high outputs.

The logic of the relation between investments and outputs is therefore related to, but different from the Bertrand case. There, investments were highest for firms in situations with high prices, because optimistic firms would chose high investments and expect to get away with high prices. Now optimistic firms expect competitors to choose low investments and low outputs. Therefore, by strategic substitutes, optimistic firms should choose high investments and high outputs.

6 Conclusion

This paper has analyzed the effects of more intense competition on investments in simple two-stage R&D models. In the first stage, firms whose marginal costs are identical ex-ante simultaneously invest in R&D. The investment leads to a decrease in marginal costs. In the second stage of the game, firms simultaneously choose quantities or prices in a homogeneous good market. We show that an increase in the number of firms tends to reduce investments, whereas a shift from Cournot to Bertrand increases investments. The latter observation is partly predicted by theory (for two firms) and partly the result of overinvestment in the Bertrand case.

[37] In the 14 cases where the average individual investment is 2, the average market output is 24.5 (as opposed to 25.6 in the continuous subgame equilibrium).

[38] The equilibrium output of firm i is $q_i = \frac{a-c}{5} + \frac{4}{5}y_i - \frac{1}{5}\sum_{j \neq i} y_j$. In an OLS regression with outputs as dependent and investments and period dummies as independent variables, the coefficients are 0.340 for y_i (significant at the 1%-level) and -0.089 for y_j (significant at the 10% -level).

A simple set of experiments cannot resolve the debate about the effects of competition on investment. First, there are conceptual ambiguities at the theoretical level. Even the definition of increasing competition is contentious, some insightful attempts to structure the debate notwithstanding.[39] Second, even for specific notions of increasing competition in two-stage games, there are many models to investigate the issue.[40] Finally, one may worry about the external validity of the laboratory setting as a means of testing predictions about the long-term strategic decisions of managers in large firms.

However, our analysis provides a clear result that is worthy of further investigation: In some situations, there are behavioral effects that support a positive effect of competition on investment.

Appendix

A.1 Tables

In column (1) we use one-stage data, in column (2) two-stage, and in column (3) we pool one- and two-stage data.

Table 7 Observed and predicted investment

Cournot $I=2$, $y_t^{i*}=2$						
	(1) Δy_t^i		(2) Δy_t^i		(3) Δy_t^i	
β_0	0.514[c]	(0.126)	0.218	(0.135)	0.366[c]	(0.097)
N	720		720		1440	
Cournot $I=4$, $y_t^{i*}=2$						
	(1) Δy_t^i		(2) Δy_t^i		(3) Δy_t^i	
β_0	−0.061	(0.154)	−0.430[a]	(0.141)	−0.245[a]	(0.119)
N	640		640		1280	
Bertrand $I=2$, $y_t^{i*}=2.62$						
	(1) Δy_t^i		(2) Δy_t^i		(3) Δy_t^i	
β_0	0.477[c]	(0.121)	0.929[c]	(0.177)	0.703[c]	(0.118)
N	720		720		1440	

[39] See for instance Boone (2000).

[40] Vives (2008) provides a unifying discussion of two-stage games, with the extent of product differentiation as an inverse measure of competition. Schmutzler (2010) extends the discussion to other measures of competition.

Table 7 (*Continued*)

Bertrand $I=4$, $y_t^{i*}=1.27$						
	(1) Δy_t^i		(2) Δy_t^i		(3) Δy_t^i	
β_0	1.152[b]	(0.297)	1.286[c]	(0.121)	1.219[c]	(0.151)
N	640		640		1280	

Standard errors in parentheses are corrected for matching group clusters
[a] $p<0.1$, [b] $p<0.05$, [c] $p<0.01$

A.2 Figures

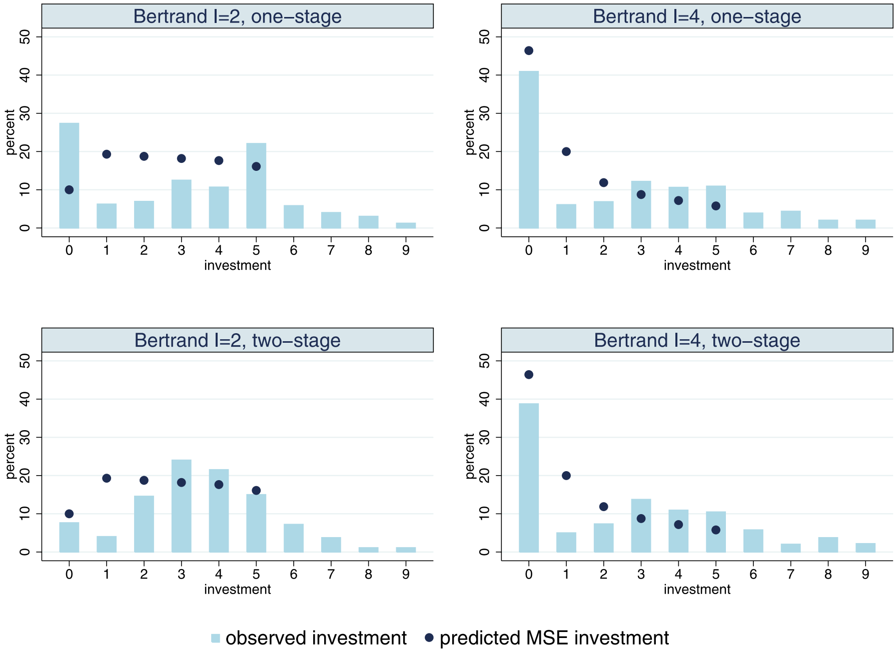

Fig. 4 Observed investment levels in all Bertrand treatments and predicted MSE investment levels

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